

EXHIBIT A

Excerpts from Streetman, Ben G., Solid State Electronic Device, Prentice-Hall, Inc., 1980, page 67.

Exhibit in Support of Response – NVX-0015C1

SOLID STATE ELECTRONIC DEVICES

second edition

BEN G. STREETMAN

Department of Electrical Engineering
The University of Texas at Austin

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Preface xv

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- 1.2 Crystal Lattices
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2 Atoms and Electron

- 2.1 Introduction to Physi
- 2.2 Experimental Observ
 - 2.2.1 The Photoelect
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When an electron is taken away from its position in the bonding band, it is free to move about in the lattice, a conduction electron. The empty bond (hole) is left behind. The energy level of the electron is the band gap energy E_g . This model helps in understanding the mechanism of EHP creation, but the energy band model is not suitable for purposes of quantitative calculation. One "bond" model is that the free electron and the hole are spread out over several lattice spacings. The electron is mechanically by probability distributed

are created in pairs, the conduction electron concentration (n per cm^3) is equal to the concentration of holes (p per cm^3). Each of these intrinsic carrier concentrations is denoted as n_i . Thus for intrinsic material,

$$n = p = n_i \quad (3.1)$$

For a certain concentration of electron-hole pairs, the carrier concentration is maintained, there is a balance between the same rate at which they are generated and the rate at which they recombine. An electron in the conduction band makes a transition to an empty state (hole) in the valence band. Let us denote the generation rate of EHP's as g and the recombination rate as r , equilibrium requires that

$$r = g \quad (3.2)$$

which is independent of temperature. For example, $g(T)$ increases with temperature and a new carrier concentration n_i is established. The recombination rate $r(T)$ just balances generation rate $g(T)$ so that the rate of recombination of electron-hole pairs is equal to the rate of generation. The equilibrium concentration of electron-hole pairs is

$$n_i p_i = n_i^2 = g_i \quad (3.3)$$

which is a function of temperature. The recombination rate r is proportional to the product of the electron and hole concentrations, which depends on the particular material. We shall discuss the calculation of the recombination rate in Section 3.3.3; recombination processes are discussed in Section 4.

When carriers are generated thermally, it is possible to maintain a certain carrier concentration by purposely introducing impurities. Doping, is the most common technique

for changing the conductivity of semiconductors. By doping, a crystal can be made so that it has a predominance of either electrons or holes. Thus there are two types of doped semiconductors, n-type (mostly electrons) and p-type (mostly holes). When a crystal is doped such that the equilibrium carrier concentrations n_0 and p_0 are different from the intrinsic carrier concentration n_i , the material is said to be *extrinsic*.

When impurities or lattice defects are introduced into an otherwise pure crystal, additional levels are created in the energy band structure, usually within the band gap. For example, an impurity from column V of the periodic table (P, As, and Sb) introduces an energy level very near the conduction band in Ge or Si. This level is filled with electrons at 0°K, and little thermal energy is required to excite these electrons to the conduction band (Fig. 3-11). Thus at about 50–100°K virtually all of the electrons in the impurity level are "donated" to the conduction band. Such an impurity level is called a *donor level*, and the column V impurities in Ge or Si are called *donor impurities*. From Fig. 3-11 we note that material doped with donor impurities can have a considerable concentration of electrons in the conduction band, even when the temperature is too low for the intrinsic EHP concentration to be appreciable. Thus semiconductors doped with a signif-

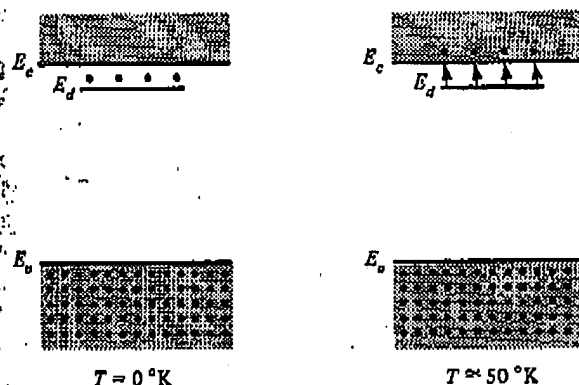


Figure 3-11. Donation of electrons from a donor level to the conduction band.

icant number of donor atoms will have $n_0 \gg (n_i, p_0)$ at room temperature. This is called *n-type material*.

Impurities from column III (B, Al, Ga, and In) introduce impurity levels in Ge or Si near the valence band. These levels are empty of electrons at 0°K (Fig. 3-12). At low temperatures, enough thermal energy is available to excite electrons from the valence band into the impurity level, leaving holes in the valence band. Since this type of impurity level "accepts"